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LABORATORY AND FIELD TESTS OF A LUNAR SURFACE NAVIGATION SYSTEM

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16. ABSTRACT

The results of laboratory and field tests on a simple dead-reckoning system that consists of a directional gyro, an odometric system, and a signal processor are presented in this report. Navigation sorties performed at the Marshall Space Flight Center, Alabama, and the United States Geological Survey, Flagstaff, Arizona, of lengths to 30 km are described, and the results are presented in detail. The use of a sun aspect compass for initial gyro alignment is described. The results of these tests offer strong corroborative proof that such a system is adequate for the initial manned lunar sorties.

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SUMMARY

The results of laboratory and field tests on a simple dead-reckoning system that consists of a directional gyro, an odometric system, and a signal processor are presented in this report. Navigation sorties performed at the Marshall Space Flight Center, Alabama, and the United States Geological Survey, Flagstaff, Arizona, of lengths to 30 km are described, and the results are presented in detail. The use of a sun aspect compass for initial gyro alignment is described. The results of these tests offer strong corroborative proof that such a system is adequate for the initial manned lunar sorties.

INTRODUCTION

Laboratory and field tests were performed on a simple dead-reckoning navigation system designed specifically to satisfy the accuracy requirements for the initial sorties of the manned lunar roving vehicle (LRV). The system consisted basically of a directional gyro, an odometric system, and a signal processor. The system is described in Reference 1.

The tests described here were performed at the Marshall Space Flight Center, Alabama, and the United States Geological Survey, Flagstaff, Arizona. The Flagstaff area was used because of the similarity of its soil and terrain to the lunar surface. Presurveyed checkpoints and maps were also available for position error determination.

The tests covered position errors, traverse closure errors, wheel slippage compensation, initial alignment, and updating the gyro with a unique sun compass arrangement. To a lesser degree, answers were provided to the question of how well a subject can navigate with a dead-reckoning system when obstacle avoidance is also present.

GENERAL DISCUSSION

Navigation System Description

The dead-reckoning navigation system prototype for the lunar roving vehicle consists of a directional gyro for establishing an inertial direction, an odometric system for measurement of distance, a signal processor for combining the measured distance and direction, and a sun compass for determining initial vehicle heading information.

The prototype system under test (Fig. 1) was assembled using components that were available in the laboratory or could be acquired easily. This resulted in some component errors being greater than desired. Realizing that these errors were excessive, however, allowed a meaningful evaluation of the operational capabilities of such a system.

The directional gyro output is from a three-wire, 400-Hz synchro transmitter (CX) illustrated in Figure 1. There was no provision for torquing the gyro for alignment, so a synchro differential transformer (CDX) was used for aligning the gyro output to the initial reference heading and for updating. A simple servoed synchro repeater provided the vehicle heading display after proper alignment.

The sun is used as the azimuth reference. Sun sensors mounted on a theodolite and driving null meters are used to measure the angle between vehicle heading and the solar subpoint, θ, to within 1 min of arc. The angle between the sun and north, ϕ, is determined from the ephemeris charts. The vehicle heading was then $\gamma = -(\phi - \theta)$. The CDX shaft is rotated until this angle is registered on the heading display.

The output of the CDX excites a Scott-T transformer that converts the three-wire synchro output to the sine and cosine of γ. These two signals are then demodulated, filtered, and scaled so that a sine or cosine value of one (90 or 0 deg) is represented by a 10-Vdc level. The signals are then changed to digital form by an analog/digital converter for processing. The functions performed by the processor are $\Delta x = \Delta s \cos \gamma$ and $\Delta y = \Delta s \sin \gamma$, and with proper scaling, northings $= \Sigma \Delta x$ and eastings $= \Sigma \Delta y$, where Δs is an increment of distance.
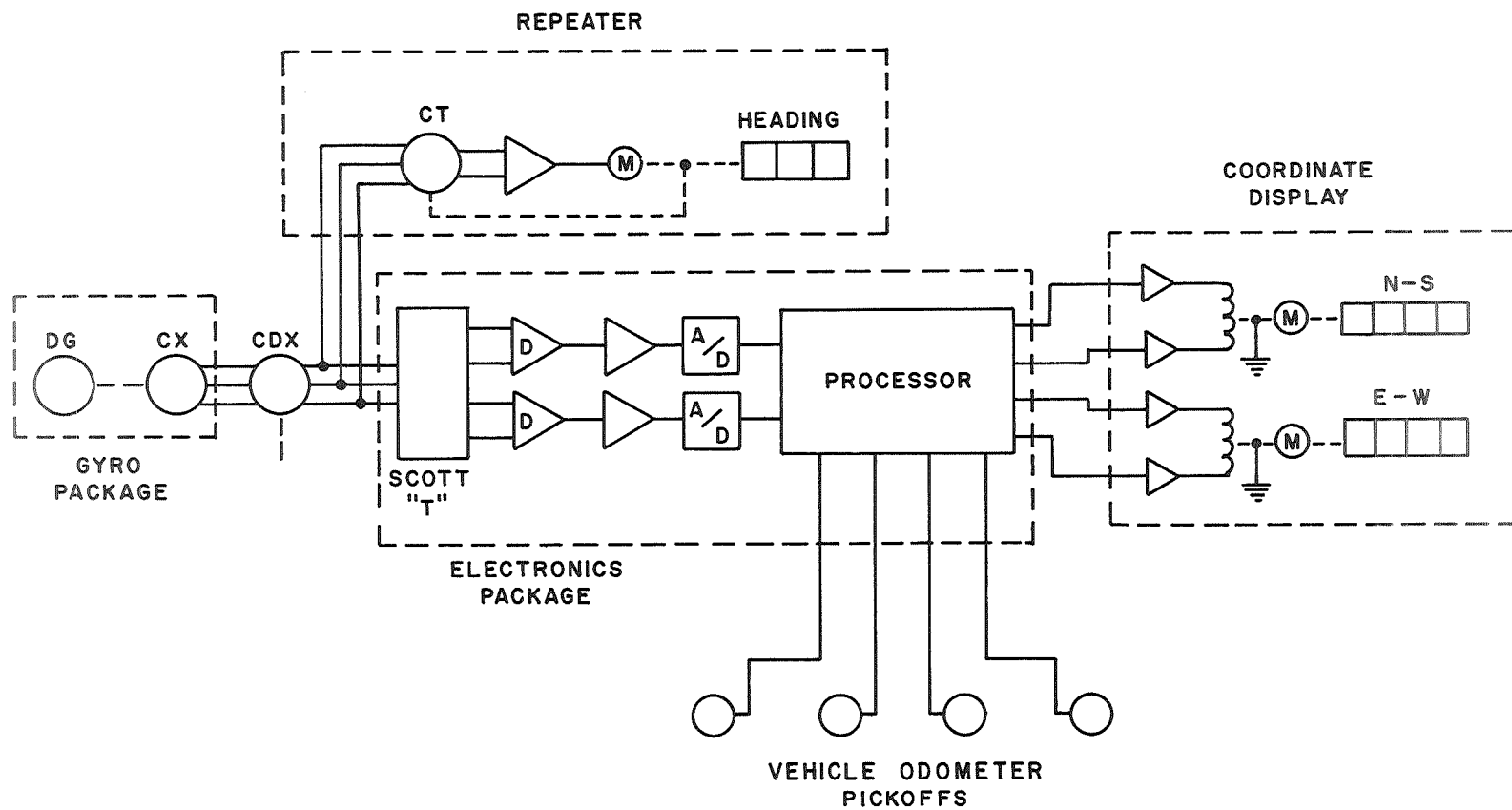
Figure 1. Hybrid coordinate resolver.

The Δs increment is produced when the third fastest wheel of an odometer produces a signal. This method permits two wheels to spin without introducing an error. The system would also operate with the loss of the odometer signal from one wheel. The vehicle motion is measured more accurately and simply than with arithmetical averaging of the odometer pulse.

Laboratory Tests

After preliminary system calibration in the laboratory, a course was laid out as shown in Figure 2 using a number of distances and angles that would simulate a test traverse. With a given gyro initial alignment, a number of pulses were put into the processor to simulate odometer measured distances. Angles were turned from the gyro heading at the end of each leg of the simulated traverse. The recorder plot of the navigation system output is shown in Figure 3. The total course of 9252 m (30 354.8 ft) had a closure error of 48.8 m (160 ft) or 0.523 percent. This error was caused by the calibration of the scaling amplifier with odometer pulses and also gyro drift during the 1 hr and 20 min run. This data plot gives a very good indication of the type of accuracies that could be attained with improved calibration, a low drift directional gyro, and under ideal terrain conditions.

Preliminary Field Tests

The preliminary field tests were designed to obtain test data to define the magnitude of major sources of error and develop calibration and test procedures to reduce these errors. The three major sources of error that all navigation systems are concerned with are (1) misalignment, (2) wheel slippage or odometer calibration, and (3) gyro drift.

Misalignment

A test traverse of 4220 m (13 845 ft) was run as shown in Figure 4. The odometer error and gyro drift were minimized with only a small odometer error and less than 0.5 deg/hr gyro drift. The misalignment error was rather large (1.5 deg). The closure error was 24.4 m (80 ft) or 0.65 percent and was caused by the small gyro drift and odometer errors. From the plot of the navigation system output for this traverse in Figure 4, it can be seen that the maximum error caused by misalignment will always be at the farthest point from the starting position. This is illustrated in the comparison of traverse A and traverse B in Figure 5.

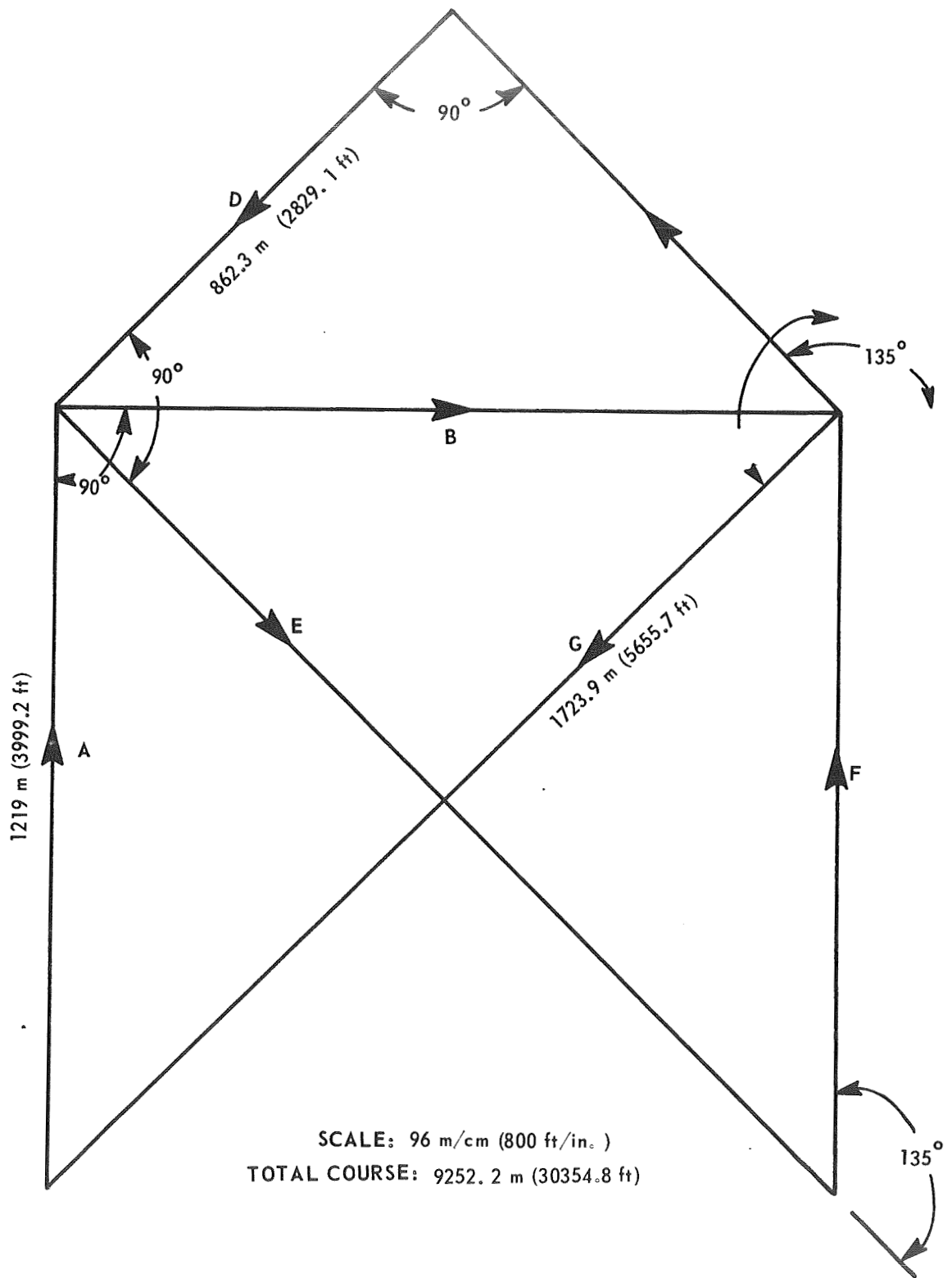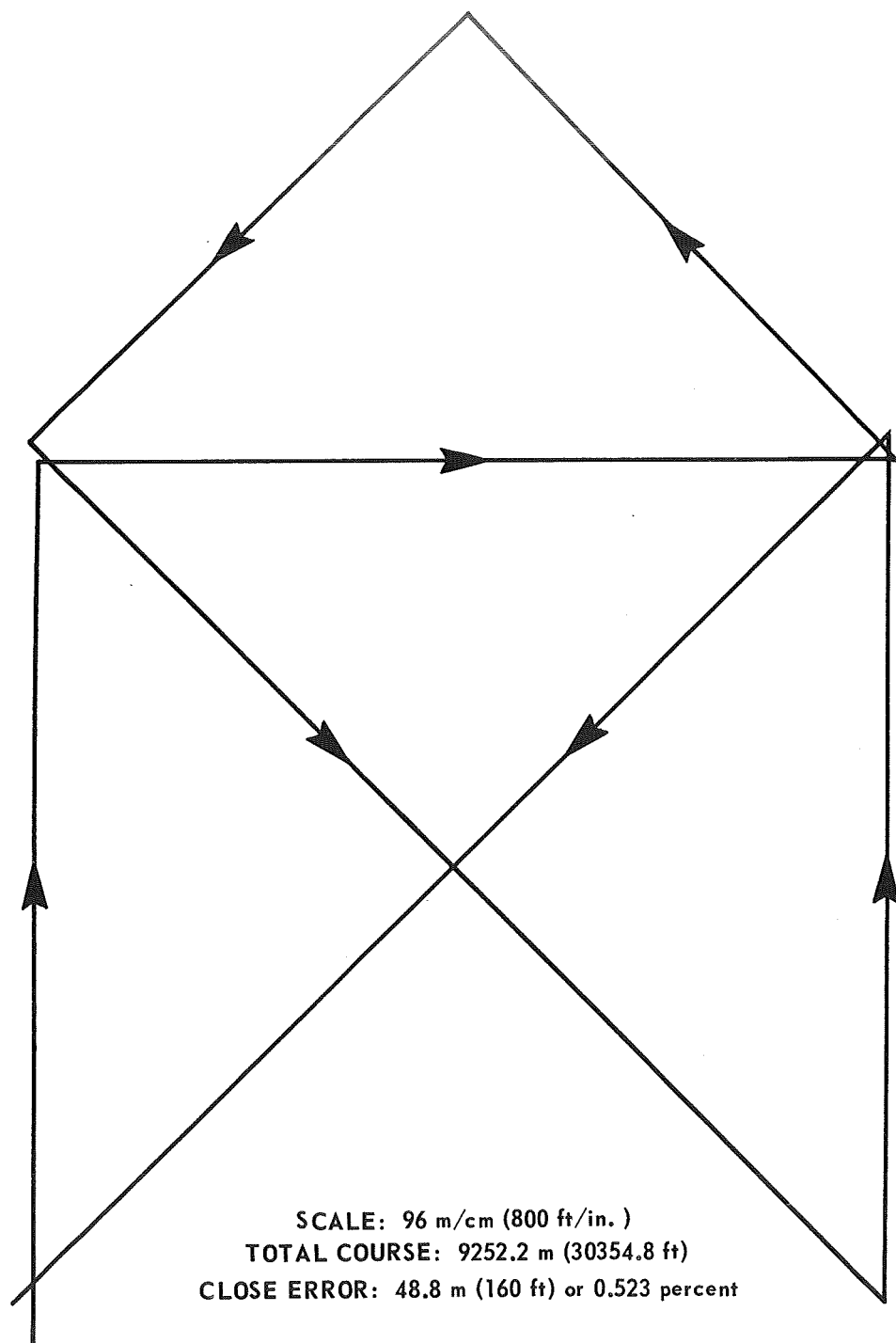Figure 2. Static laboratory tests on the LRV navigation system.

SCALE: 96 m/cm (800 ft/in.)
TOTAL COURSE: 9252.2 m (30354.8 ft)
CLOSE ERROR: 48.8 m (160 ft) or 0.523 percent

Figure 3. Preliminary static laboratory tests
on the LRV navigation system.

4 CIRCLES FOR PHOTOGRAPHER

1st RUN
MARCH 6, 1970

SCALE: 96 m/cm (800 ft/in.)
TOTAL COURSE: 4220 m (13845 ft)
CLOSE ERROR: 24.4 m (80 ft) or 0.65 percent
ALIGNMENT ERROR: 1.5°
TIME: 45 minutes
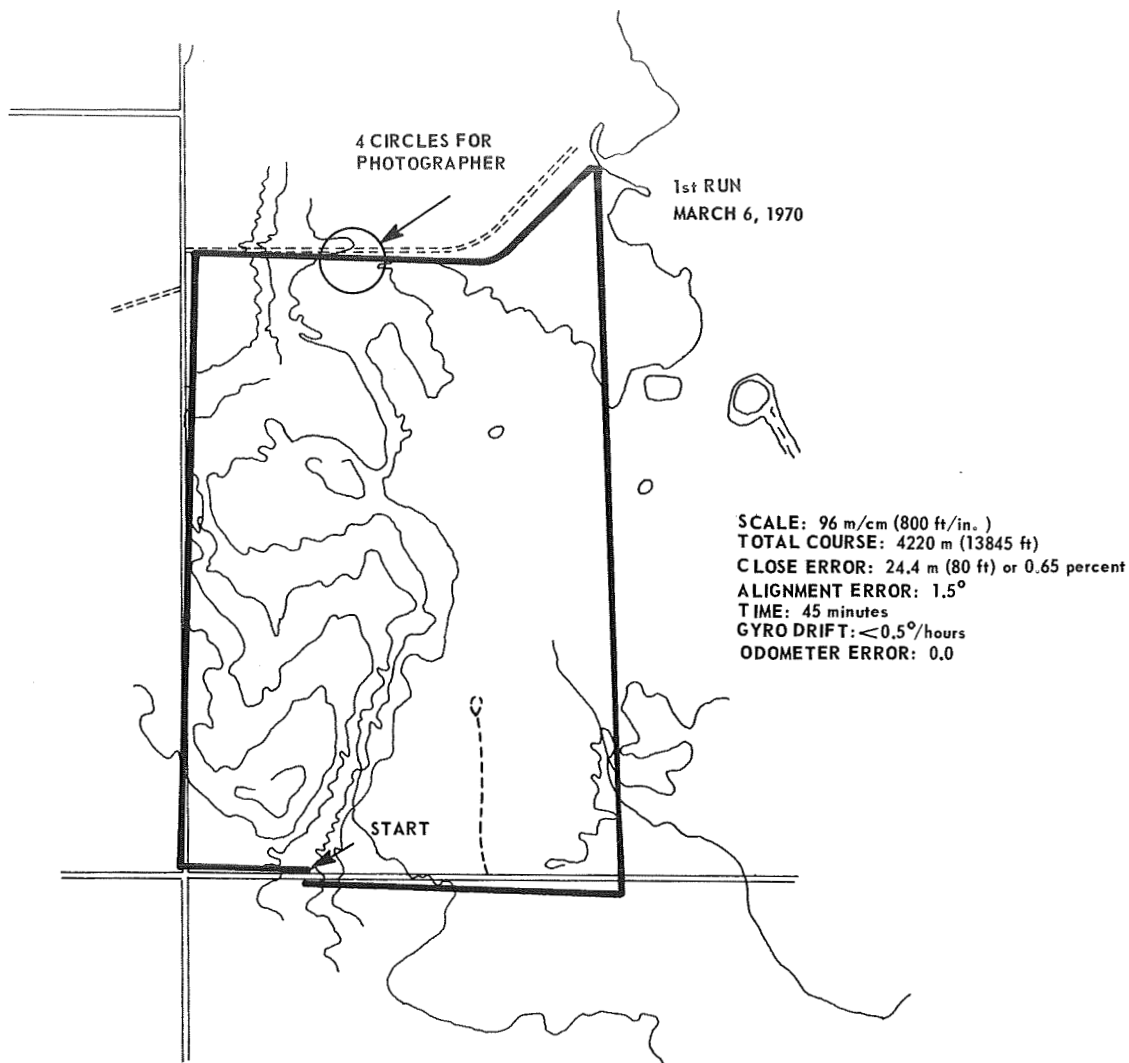GYRO DRIFT: <0.5°/hours
ODOMETER ERROR: 0.0

START

Figure 4. Preliminary field test on the LRV navigation system.

Odometer Calibration

A test traverse of 4220 m (13 485 ft) was run as shown in Figure 6. For this run the alignment error and gyro drift were minimized with only a small alignment error (< 0.1 deg) and less than 0.5 deg/hr gyro drift. The odometer calibration error for this particular run was rather large (5.8 percent). The closure error of 59.4 m (195 ft) or 1.45 percent of the distance traveled was caused primarily by the odometer calibration error. Again the maximum error caused by odometer calibration error, or wheel slippage, was at the

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TRAVERSE A →

TRAVERSE B →

TRAVERSE C →

TRAVERSE A = NO ERROR

TRAVERSE B = MISALIGNMENT
TO LEFT

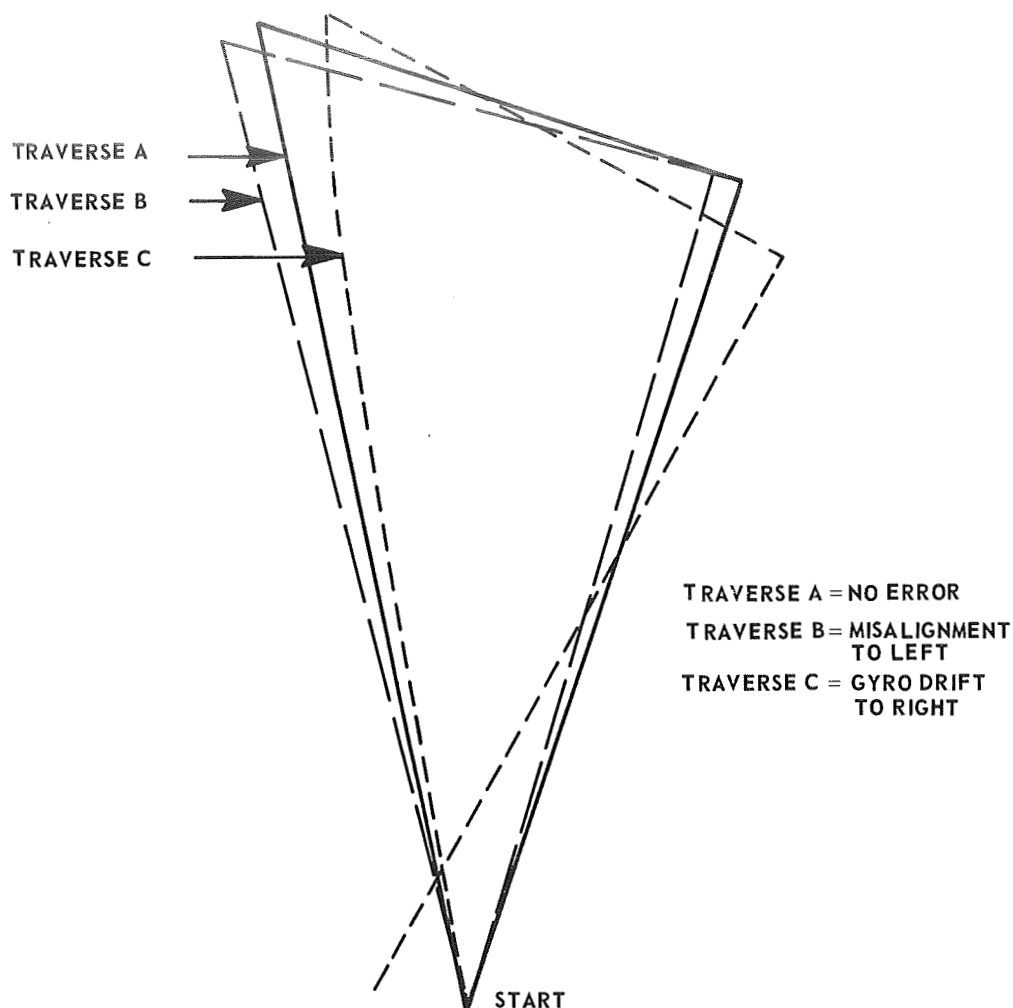TRAVERSE C = GYRO DRIFT
TO RIGHT

START

Figure 5.   Traverse errors caused by misalignment and gyro drift.

farthest point from the starting position.   This error tends to partially cancel
out on the return path to the starting position but not nearly as well as the
errors of misalignment.

An interesting observation was made on wheel slippage that was useful
in later distance measurements.   As the test equipment was unloaded at
Flagstaff, a calibration test was run on the blacktop roads, and the scaling
was adjusted for correct measurement of distance.   The test equipment was
then transported to the test area which consisted of black, volcanic, loose
cinders.   Several calibration runs on this type of soil were made on nearly
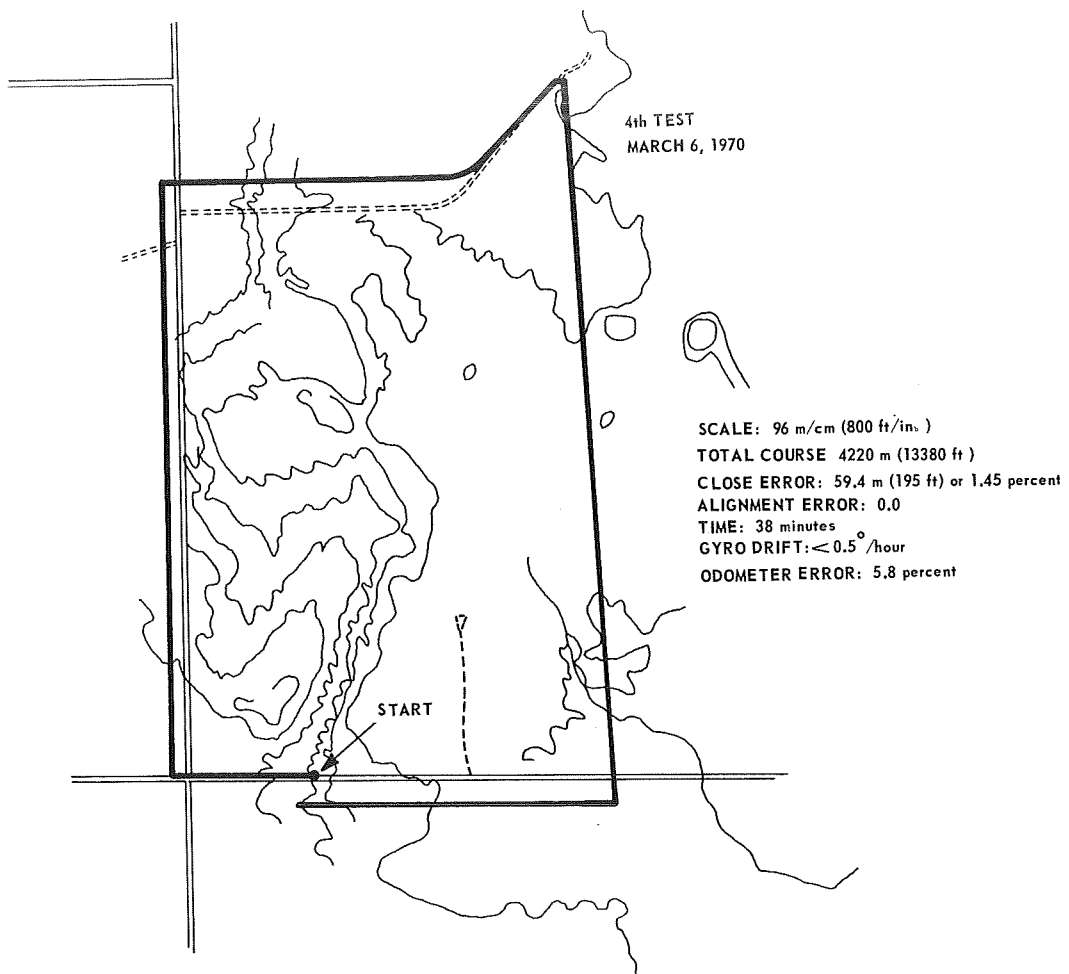level terrain.   The calibration change required to give true measured

4th TEST
MARCH 6, 1970

SCALE: 96 m/cm (800 ft/in.)
TOTAL COURSE 4220 m (13380 ft)
CLOSE ERROR: 59.4 m (195 ft) or 1.45 percent
ALIGNMENT ERROR: 0.0
TIME: 38 minutes
GYRO DRIFT: < 0.5°/hour
ODOMETER ERROR: 5.8 percent

START

Figure 6. Preliminary field test on the LRV navigation system.

distance was 3. 7 percent. This was confirmed in later discussions with per-
sonnel at Flagstaff, since they were required to change the calibration on
their vehicle odometers an average of 4 percent between blacktop roads and
cinder roads.

Gyro Drift

Gyro drift is the most critical of the major error sources since it is
a continuously accumulating error. As the traverse time becomes longer
the error at the end of the traverse becomes larger. This is shown clearly
by comparing traverses A and C of Figure 5.

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The gyro used in this system was of 1959 vintage and had been run hundreds of hours. The gyro drift changed with temperature throughout an operating day with no temperature control. The day-to-day repeatability was very good. One reason for the test was to determine the performance of such a system with relatively crude components. The idea was to calculate the earth's rate at a given latitude and adjust the mass unbalance to compensate for it and the fixed bias drift. The remaining error would be the random drift that is usually small for a better grade of gyro. This can be done because this type of navigation system always operates in the same attitude. This approach cannot be used in other systems because it would cause greater errors in certain attitudes in an all-attitude system.

The compensating error technique was very successful for operation in a given latitude; however, the gyro drift did increase during an 8-hour operating day from < 0.5 deg/hr to 2.5 deg/hr with a temperature variation from 1.7°C in the morning to 23.9°C in the afternoon.

Sun Compass

The sun aspect compass is shown in Figure 7. The two-axis sun sensor was mounted and aligned to the optical axis of the theodolite. Two microammeters were used to read the null of the vertical and azimuth axes. The vernier adjustments of the theodolite were used for tracking the sun until a given time was read. The sun angle with respect to the vehicle headings was read and subtracted from the sun angle with respect to north obtained from the ephemeris charts. The accuracy was more than adequate for any field test alignment since most directional gyro readouts are not less than 0.1 deg scaling. The accuracy of the sun aspect compass in field test conditions with different operators has been better than 5 arc min. These tests were performed on the test vehicle with the vehicle suspension system and shock mounts causing usual leveling problems.

FIELD TESTS AT FLAGSTAFF

The 12-km traverse, as plotted by the recorder readout and shown in Figure 8, was typical of the data obtained after several calibration runs. This traverse shows small errors in misalignment, gyro drift, and odometer calibration (wheel slippage).

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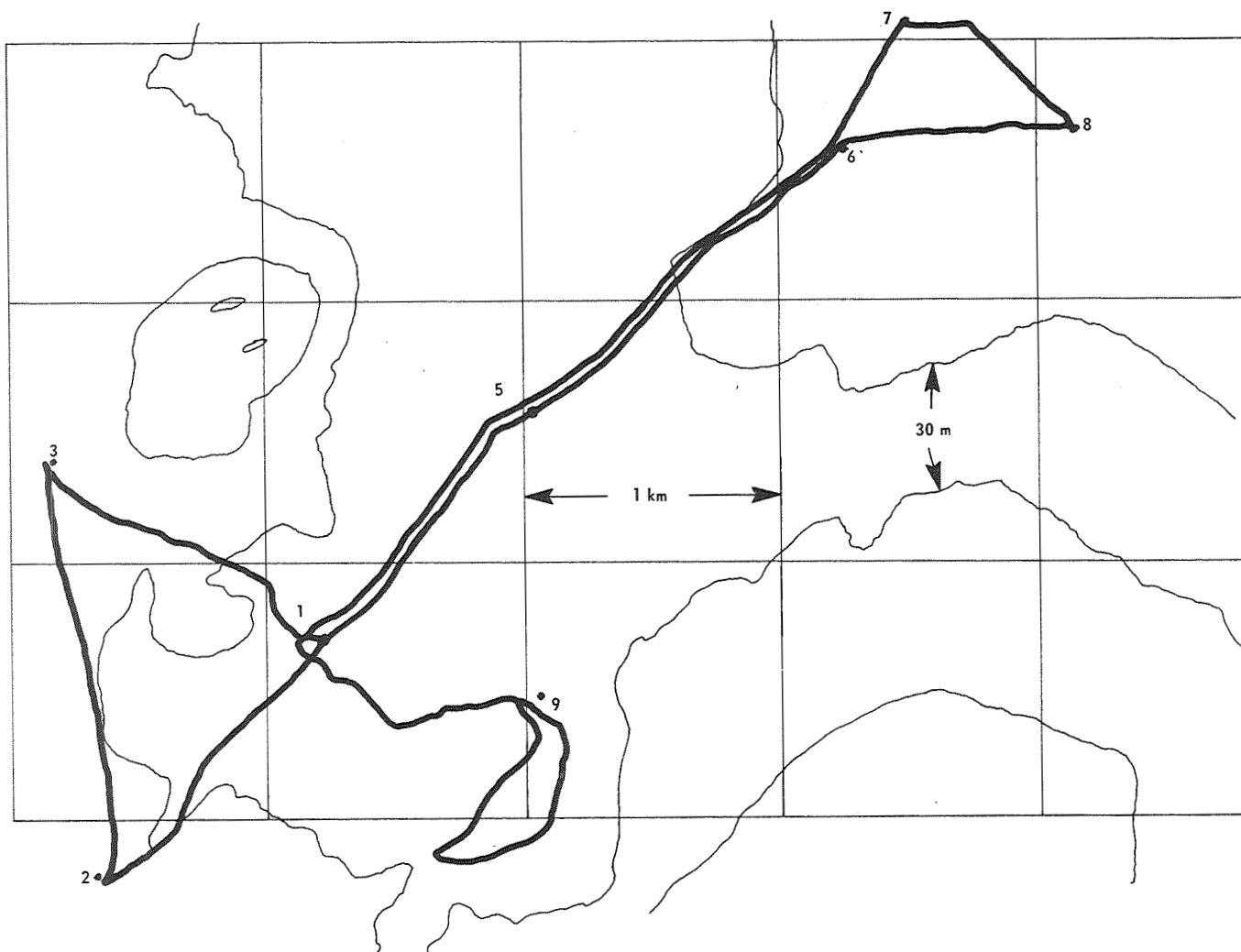Figure 7. Breadboard LRV navigation system.

Figure 8. 12-km traverse, no. 10, March 26, 1970

Starting at checkpoint 1 and proceeding to 2, 3, and back to 1 on the first leg of the traverse, one finds very little gyro drift and odometer calibration error, but a 1.5 deg misalignment error exists. Following the true characteristics of the misalignment error, it cancelled out on return to checkpoint 1.

On progressing to checkpoints 5, 6, 7, 8, and returning to 1, one finds the gyro drift has increased to 1.5 deg and is in the opposite direction to the beginning misalignment. The return error to checkpoint 1 is 80 m. For the most part, this error was a result of gyro drift caused by temperature changes.

The 60-m overrun on the return to checkpoint 1 was caused by wheel slippage. From the plot of the measured traverse in Figure 8, one finds that the distance measurement was short going from checkpoint 1 to checkpoint 7 down a 3 percent grade. On the return to checkpoint 1 back up the 3 percent grade, the wheel slippage caused an overmeasurement of distance. This error is rather small for long grades of < 5 percent with an occasional short grade up to 40 and 50 percent. With obstacle avoidance equipment, the major portion of the path chosen for exploration will be low grades with occasional grades for short distances up to 50 percent. As the grades approach 66 percent, or 30 deg, it becomes apparent that a dangerous action is in progress, and these steep grades will normally be avoided as much as possible, particularly for long distances.

The long traverse of 32 km was run, and each checkpoint error was plotted as shown in Figure 9. The traverse was started at checkpoint 1 at 10:40 a.m. The initial alignment and odometer calibration were very good with very little gyro drift as indicated between checkpoint 1 and checkpoint 7. By 11:35 a.m. at checkpoint 8, the gyro temperature had risen and the drift had started to increase. For the 5-hour traverse and an ambient temperature increase of 1.7°C, the drift error had increased to 11.5 deg, or an average of better than 2 deg/hr. There was no gyro updating with the sun compass, and no corrections were made in any fashion.

The point-to-point distance measurement error, as shown in Figure 10, averaged less than 2 percent with some elevation changes as much as 91.4 m (300 ft). These elevation changes contributed to the odometer measurement error by wheel slippage and vertical angle error. Figure 10 also shows the angular-distance error buildup at each checkpoint caused by gyro drift.
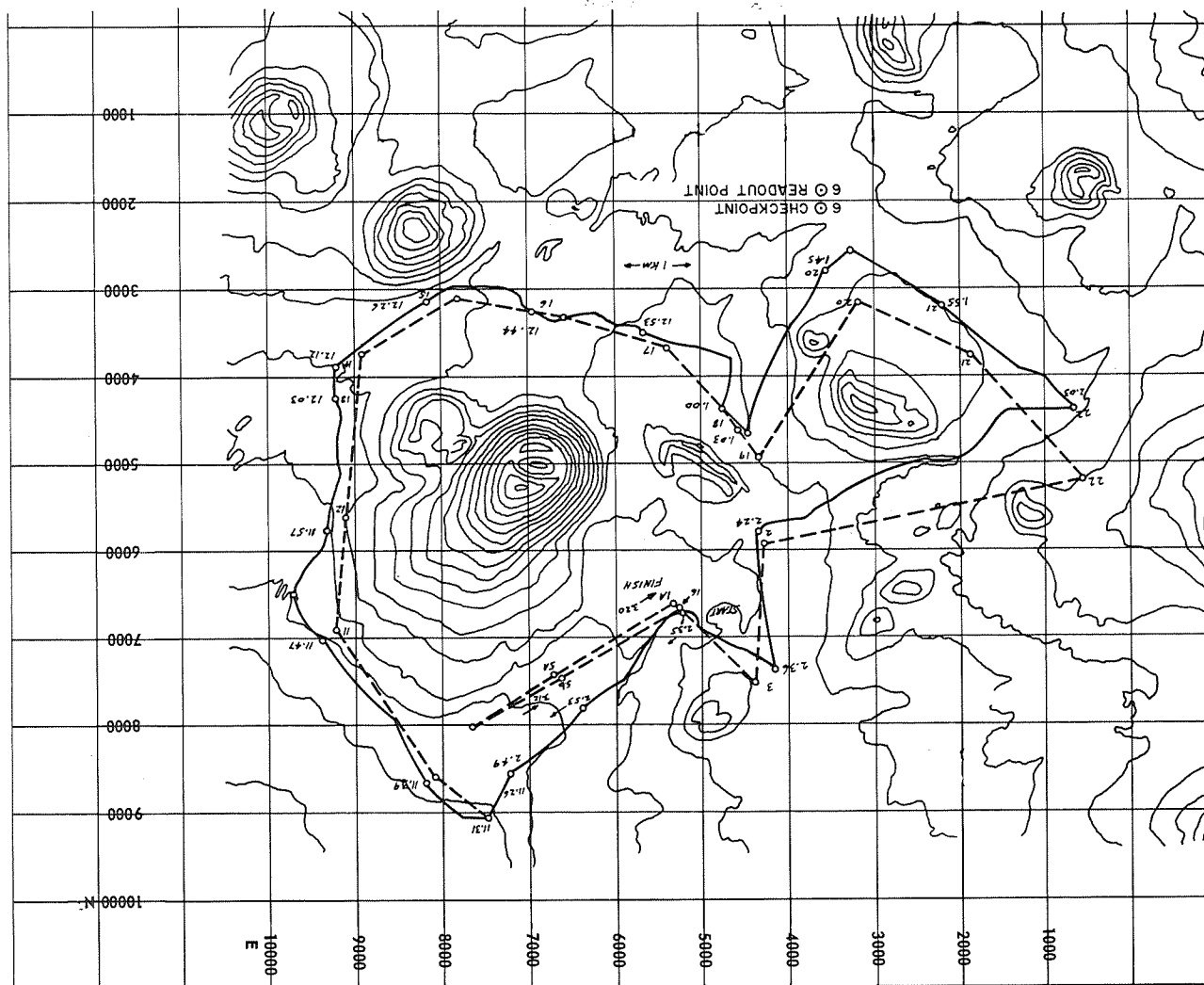
13

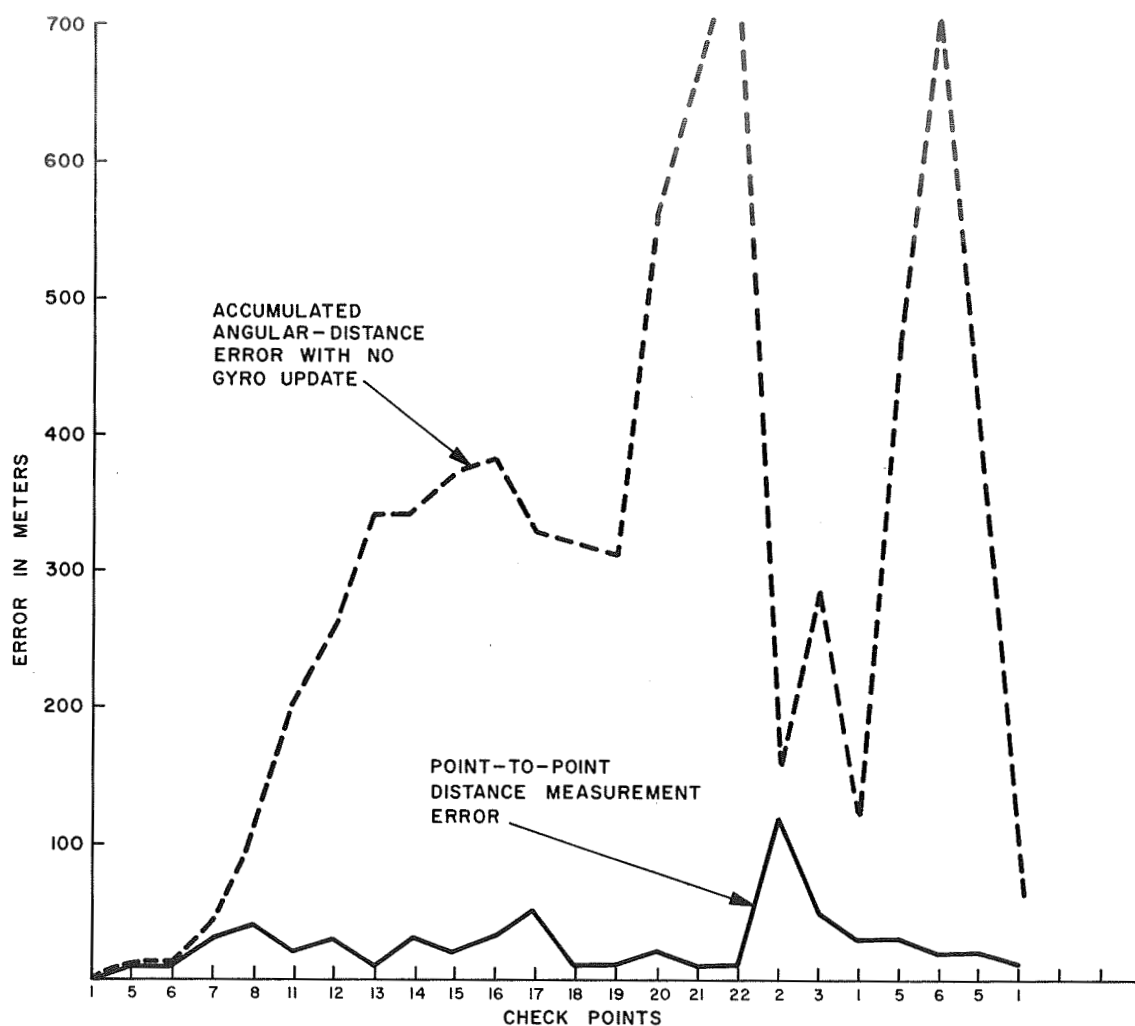Figure 9. 32-km traverse, no. 11, March 26, 1970

Figure 10. 32-km traverse, no. 11, March 26, 1970

Identical tests were performed on a 12-km traverse using gyro alignment updating in one case and no alignment updating in the other. These tests proved that the error caused by gyro drift can be held below 1.0 percent with periodic gyro alignment updating.

CONCLUSIONS

Field testing such a simple dead-reckoning navigation system has proven that with a temperature controlled gyro, odometer calibration, sun compass alignment, and updating, a 30-km traverse can be made with less than a 2 percent overall error with these same test conditions.

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    MSFC Experimental Development Program for Lunar Surface
    Navigation Equipment. NASA TM X-64509, April 30, 1970.

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LABORATORY AND FIELD TESTS OF A
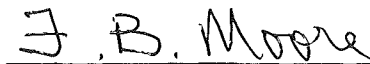# LUNAR SURFACE NAVIGATION SYSTEM

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